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REPORT

CD NO.

COUNTRY	USSR	DATE OF INFORMATION	1948
SUBJECT	Geophysics		
HOW PUBLISHED	Periodical	DATE DIST.	11 January 1949
WHERE PUBLISHED	Moscow	NO. OF PAGES	10
DATE PUBLISHED	April 1948		
LANGUAGE	Russian	SUPPLEMENT TO REPORT NO.	

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SOURCE <u>Izvestiya Akademii Nauk SSSR, Seriya Geograficheskaya i Geofizicheskaya</u>, (News of the Academy of Sciences USSR, Geography and Geophysics Series) Vol XII, No 2, 1948. (FDB Per Abs 41T50 -- Translation specifically requested.)

A NEW METHOD FOR STUDYING WEAK CHANGES IN THE EARTH'S MAGNETIC FIELD

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Submitted 24 November 1947

/Figures referred to herein are appended./

There are a great number of geophysical phenomena which are accompanied by very weak variations of the intensity of the earth's magnetic field. Among those are, first of all, phenomena connected with changes of ionization of the upper atmospheric layer, and also phenomena which can be determined by changes in magnetization of the upper strata of the earth's crust.

As an example of the first group of phenomena, we may point to the magnetic effect of a solar eclipse, which geophysicists and astronomers have been trying to observe and measure during the past 50 years. There is no accurate account of the extent of this effect. However, there are indications (e.g. by Chapman) of the upper and lower limits: from 2-3 up to 14-15 γ. Consequently, the total effect of a solar eclipse is considerably less than the daily variations of the earth's magnetism and, considering the sensitivity of the present magnetometric instruments, it cannot be clearly detected.

The sensitivity of variometrical instruments, intended for registering variations of the earth's magnetism, is at the moment between the limits of two to four γ to 1 millimeter of the scale. As we know, modern variometers are based on the magnetostatic principle; a permanent magnet suspended on a torsion device indicates the changes of one or another element of the earth's magnetic field. This principle does not permit the sensitivity of the variometrical instruments to increase to such an extent that they could be used for registering very weak changes in a magnetic field.

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It is, however, possible to detect small changes in the intensity of the field, by measuring the changes of a magnetic current through a large induction coil with a fluxmeter.

The method we suggest is basically as follows: take a large coil of insulated wire and place it in the earth's magnetic field; then any change in the intensity of the earth's magnetic field will change the magnetic current through the coil. Such change of current will be proportional to the surface of the coil and the number of turns. Let us suppose that we take a coil with a surface of one million square centimeters and with a number of turns equaling 100. In that case the constant of the coil will be 10^8 square centimeters.

If the intensity of the earth's field is changed by one gamma, the magnetic current through the coil will change by 1,000 maxwell. This quantity can easily be determined by fluxmeters.

If we connect such a coil with a sensitive fluxmeter, weak changes of the magnetic field can be determined by the cited device. The magnetometric station of the Geophysical Institute was designed on this principle. This station was originally built in 1945 at the suburban base of the magnetic laboratory. It was intended that construction be completed by 9 July 1945 to determine the magnetic effect of the solar eclipse with the new apparatus. However, the station had not been completed by that time and it was only possible to test the usefulness of the principle itself without proving its accuracy. We were nevertheless able to show that the method referred to had unlimited possibilities with regard to increasing the sensitivity of equipment for observing slight variations of the earth's magnetic field.

During the next 2 years we improved the equipment and we now have a station which works almost automatically, and which makes it possible to register exceptionally fine changes of the magnetic field.

As an example of the work being done, we cite the synchronous recordings of changes in the magnetic field made at our station and at the station of the Institute of Terrestrial Magnetism at Krasnaya Pakhra (Figure 1). At our station the recordings were made with two coils: a large one with 36 turns, and a small one with two turns. The scale of the recordings is shown on the left. By comparing the scales, we see that the sensitivity of the large coil at our station is approximately 100 times greater than that of the recording device at the Institute of Terrestrial Magnetism.

In comparing the three recordings shown in the diagram, we must keep in mind that the zero lines of the recordings at our station do not appear as straight lines; therefore, if the highest and lowest points of all three curves coincide, their relation to the zero lines, shown in the diagram as straight lines, does not always coincide (The general plan of the geomagnetic station is shown in Figure 2.)

The dotted rectangle in the diagram shows the induction coils, which are susceptible to changes in the field. They are located approximately one kilometer from the station building in the woods, and are made of lead-covered, 19-core cable, placed in the earth at a depth of 0.5 meters. The diameter of the coils is 100 meters; the large coil has 36 turns, the small one 2 turns. The coils are connected by cable with the station building where the sensitive fluxmeters are located. The total surface of the turns of the large coil is $2,827 \cdot 10^9$ square centimeters, and the total surface of the turns of the small coil is $1.57 \cdot 10^8$ square centimeters. The sensitivity of the fluxmeter connected with the larger coil is 374 maxwell to 1 millimeter of the scale, and the sensitivity of the fluxmeter connected with the small coil is 250 maxwell to 1 millimeter of the scale.

The constants of the induction coils and the sensitivity of the fluxmeters insure the sensitivity of the entire apparatus to changes in the earth's magnetic field as follows: for the large coil a sensitivity of $1.32 \cdot 10^{-7}$ oersted to 1 millimeter of the scale, and for the small coil $1.59 \cdot 10^{-6}$ to 1 millimeter of the scale, with an accuracy of ± 15 percent. In other words, the sensitivity of our magnetic station is two degrees higher than that of the magnetostatic instruments used at the best modern geophysical-magnetic stations.

The coil-fluxmeter system, therefore, forms the basis of our method for detecting and measuring slight variations of the earth's magnetic field.

For the purpose of registering changes in the field there is installed at the station an automatic recording device with a time indicator. On the left side of Figure 2 is shown a fluxmeter with an illuminator, and on the right side a self-recording device, where the changes in deflection of the light indicator of the fluxmeter are recorded on light-sensitive paper, moving at a constant speed.

The size of the scale of the self-recording device is 16 centimeters. For this reason it is possible to register changes in the field, on the entire length of the scale with a quantity of only one γ, as a higher degree of variations in the field would place the light indicator of the fluxmeter outside the range of the scale. In order to extend the range of the recordings, as the light indicator approaches either edge of the scale, the direction of the current in the circuit of coil-fluxmeter is reversed and the light indicator goes to the other side, continuing to record the corresponding changes in the field. By the process of switching the current, we have widened the range of the scale considerably, with instruments of such great sensitivity we can record any degree of variation in the magnetic field, up to tens and hundreds of gammas.

The true values of the variations are, of course, obtained through further processing of the photo-recording. This involves taking out the recording at the places where the current was switched and determining its range.

During the early stage of the work at the station, the observer followed the indicator on the scale and, at the appropriate moment, switched the current. When work is continuous, such a procedure becomes tiresome, and it was suggested that the current switching be made automatic, by means of a photocell. The photocells are installed at the edges of the scale and they automatically cut in the relay, switching the current in one or the other direction, as soon as the photocell is touched by the light indicator of the fluxmeter.

The self-recording device operates at several speeds and can shift the tape at a speed of 1.3 millimeters to 36 centimeters per minute. This makes it possible to record very rapid variations of the earth's field. Figure 3 shows part of the tape recording of variations in the earth's field. The photographic recording also always indicates time intervals with the aid of a simple device operating from an electric clock (Figure 2).

A magnetometric device with such sensitivity actually enables us to record minute changes in the earth's magnetic field. We were convinced of this possibility during the early stage of our work at the station when it was partially completed (9 July 1945) (Figure 4 shows the processed magnetogram of the earth's field during a solar eclipse.).

As the circuit of the coil-fluxmeter, at that time, was polymetallic, parasitic thermo-electromotive forces could occur. This affected the exact quantitative results of the recordings; however, the magnetogram undoubtedly records the qualitative character of the changes in the field during eclipse. In as much as we know the moments of corpuscular and ionospheric eclipse for photons, we could compare changes in the field with these moments.

The only conclusion to be made from this observation is as follows: at the time of corpuscular and ionospheric eclipses the vertical component is increased, and at the same time this increase is considerably less for corpuscular eclipses than in the case of an ionospheric eclipse.

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Before the observation of the solar eclipse there was a heavy thunderstorm. At every discharge of lightning the intensity of the magnetic field was changed. This magnetic effect of the lightning could be recorded on our self-recording device. At this time two coils were in operation for registering changes of the vertical and horizontal components of the magnetic field (Figure 5 shows a record of changes in the field during discharges of lightning).

As seen from the scale, these changes range as low as a tenth part of a gamma, for comparatively distant discharges of lightning. For near discharges, the change in the field was very great and the fluxmeter indicator extended beyond the scale. It is interesting to note that in some instances, after a powerful discharge of lightning, the degree of intensity of the magnetic field did not return to its original value.

In 1946, during the night of 9-10 October, it was anticipated that the earth would pass through a meteorite shower. We meant to determine whether this phenomenon would be accompanied by changes in the magnetic field. The station operated all night and the recordings are shown on Figure 6.

This increase of the vertical component began around 0200 on 10 October; having reached a certain point, this increase remained permanent until 12 noon on the same day, and then started to decline. This recording was compared with recordings of the magnetostatic instruments at the Institute of Terrestrial Magnetism and there was complete conformity between the individual high and low points. However, there was no absolute coincidence of the figures showing changes in the field on both recordings; this was explained by the presence of parasitic electromotive forces in the coil-fluxmeter circuit.

On 17 February 1947, an aurora borealis was observed in Moscow. The station started observation work from 0300. The record of changes in the magnetic field during that night is shown on Figure 7.

In comparing the records with the magnetograms of the Institute of Terrestrial Magnetism, complete coincidence of the high and low points in the disturbed field could be found, both in regard to value and time.

The connection between the cited geophysical phenomena and changes in the earth's magnetic field, as recorded by our station, can apparently be explained by changes of ionization of the upper atmospheric layers and the movement of the resulting charges. With regard to the influence of lightning on the earth's magnetic field, this, of course, is the direct action of the current flowing through a flash of lightning.

Changes in the earth's magnetic field can be caused by physical phenomena occurring not only in the atmosphere, but in the earth. Nonstationary thermic, seismic, and electric processes must to some extent affect the magnetization of the rocks composing the upper strata of the earth.

The effect of change in magnetization of magnetite due to compression has long been established in the laboratory. In the magnetic laboratory of the Institute of Geophysics this effect was confirmed by the research work of M. A. Grabovskiy, who determined that when a magnetite core is subjected to a measure of 300 kilograms per square centimeter, its magnetization in strong fields is decreased by 20-25 percent. Rock formations, such as granite, etc., which as a rule contain grains of magnetite and sustaining great pressures from the strata lying above, must change their magnetization if the pressure or elastic intensity varies.

Since it is quite probable that seismic phenomena result from changes of elastic intensity in plutonic rocks, one must assume that these phenomena are accompanied by changes of the magnetization of such rocks. To confirm this assumption, we carried out a number of explosions on the surface of the soil, outside and inside induction coils, during April 1947. Naturally, the physical conditions prevailing at the time of explosions on the surface are probably very much different from the physical conditions at the time of seismic phenomena, caused by plutonic processes. Nevertheless, there is undoubtedly a connection between the two types of phenomena (Figure 8 shows recordings of variations in the magnetic field during three explosions, which were registered at different speeds of the self-recorder tape but reduced to the same scale of time).

The magneto-seismic effect recorded on these magnetograms may be explained in two ways: (1) this effect may be the result of periodic changes in magnetization of the soil in the area of the coil, under the influence of periodically changing elastic intensities due to the explosion in the upper strata of the earth; and (2) it can be the result of expansion and compression of the turns of the coil itself under the influence of the explosive wave in the soil.

The experiments necessary to determine the actual cause of these fluctuations of magnetic current through induction coils at the time of explosion will be carried out.

We are convinced that in regions with magnetic anomalies, where the upper strata of the earth are composed of rocks having a fairly high degree of magnetization, any change of the elastic intensity, such as an earthquake, will cause changes in the magnetic field, which can easily be recorded by our instruments.

In this way, the method of investigating fine variations of the earth's field, prepared by the magnetic laboratory of the Institute of Geophysics, makes it possible to show the connection between a number of geophysical phenomena occurring both in the atmosphere and beneath the earth's crust.

The equipment described above has the disadvantage that in registering changes of the field's intensity, the recording is influenced by two types of interference: firstly, the recording is systematically distorted by the torsional moment of the suspension device of the fluxmeter frame; and, secondly, the electromotive force originating in the coil from changes in the field can be interfered with by an electromotive force originating in the contacts between various metals of the circuit, and also from changes in temperature.

The first cause of error can always be calculated from the general fluxmeter theory developed by us. We might mention that the amount of error caused by the influence of the torsional moment is very slight; even with very slow changes in the field it does not exceed 10 percent of the measured quantity.

The second cause, the parasitic electromotive forces in the circuit, can be opposed in two ways. In the first place, the circuit, induction coil-fluxmeter, should be of one metal (without soldering and with no other conductors). At our station the entire circuit consists of red copper. All connections, with the exception of the junctions of the leads to the fluxmeter clamps and to the switch terminals, are made by welding the copper conductors. This reduces to a minimum the magnitude of parasitic electromotive forces in the circuit, caused by variations in temperature of its separate parts.

In cases where it is necessary to determine the presence of parasitic electromotive forces in the circuit and their total magnitude, a device with two identical induction coils, placed one on the other can be used. In this case, one coil is connected with one fluxmeter, and the other coil with the other fluxmeter. By connecting these coils with each other for a short time during the period of recording, we thus exclude completely the electromotive force arising from changes in the earth's magnetic field.

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By this method of connecting two induction coils with each other, the fluxmeters will be influenced only by the parasitic electromotive forces. In view of the fact that they have a constant value during a more or less prolonged period of time, it is possible to register them and make allowances when processing the recordings.

Consequently, when we find it necessary to have exact values of the field at a certain moment, the interferences arising from structural peculiarities of the instruments and from parasitic electromotive forces, can be discounted to some extent, and in this way we can determine the true magnitude of the changes in the field.

In conclusion, I consider it necessary to mention the great amount of work done in constructing and setting up the station with the equipment built, adjusted and tested by laboratory and by scientific workers of the magnetic laboratory at the Institute of Geophysics of the Academy of Sciences USSR, namely: G. V. Groshevoy, G. M. Ivanov, M. A. Grabovskiy, G. N. Petrova, and especially the head of the laboratory at the suburban base, Eng S. V. Tolkachev.

[Appended figures follow]

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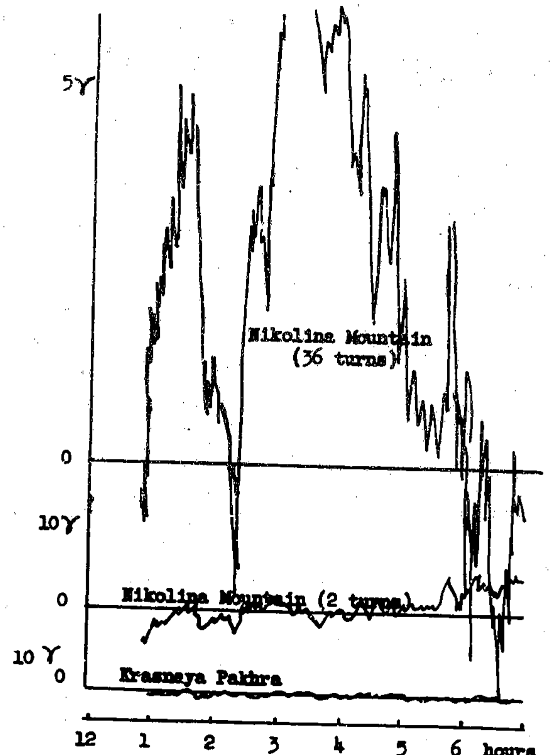

Figure 1. Variations of Z (27 April 1947) recorded at the Geophysical Institute Station on Nikolina Mountain (near Moscow); synchronous recording of the magnetostatic variometer of the Institute of Terrestrial Magnetism at Krasnaya Pakhra

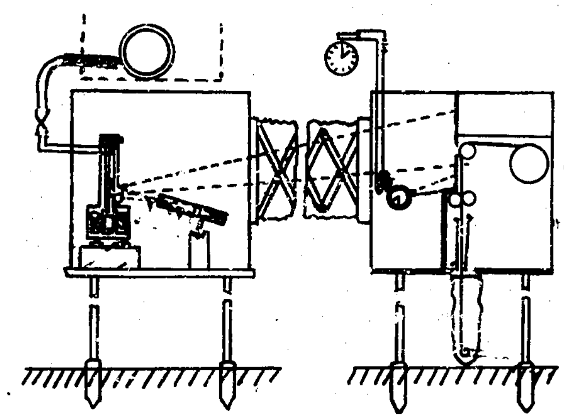

Figure 2. Plan of the Geomagnetic Station at the Geophysical Institute, Academy of Sciences USSR

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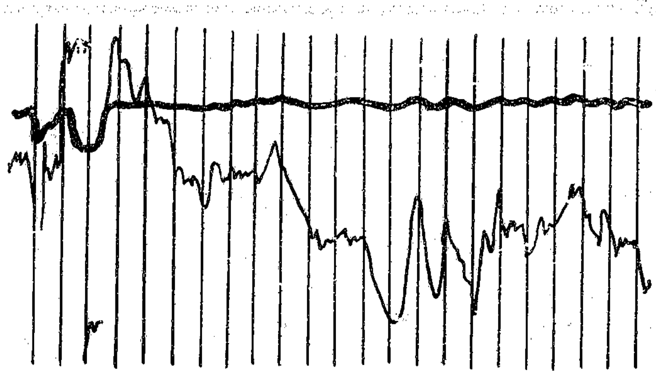

Figure 3. Variations of the Earth's Field (part of recording): thick line, recording of the coil with two turns (sensitivity 0.31 γ millimeters); thin line, recording of the coil with 36 turns (sensitivity, 0.26 γ millimeters); vertical lines, time marks at one-minute intervals.

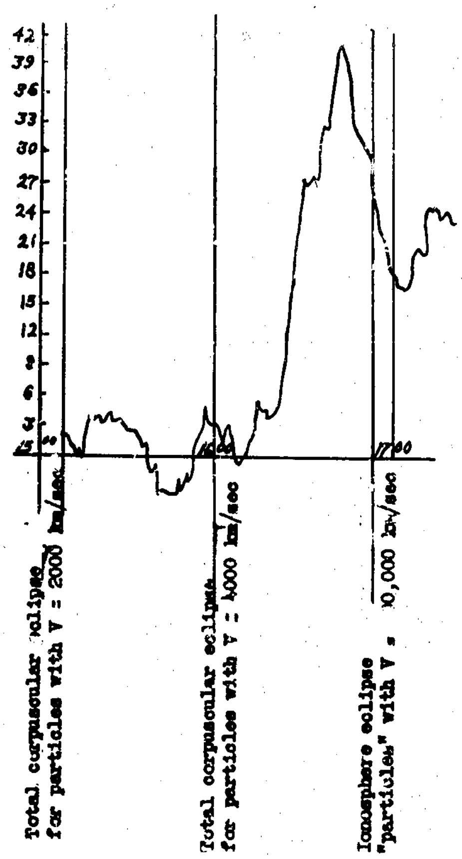

Figure 4. Variations of Z at the Time of Solar Eclipse (scale in gammas)

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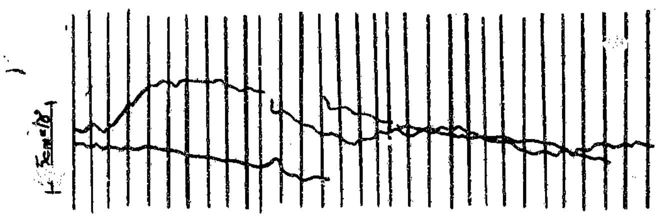

Figure 5. Variations of Z and H During a Thunderstorm
Continuous Line, changes of Z; interrupted line, changes of H

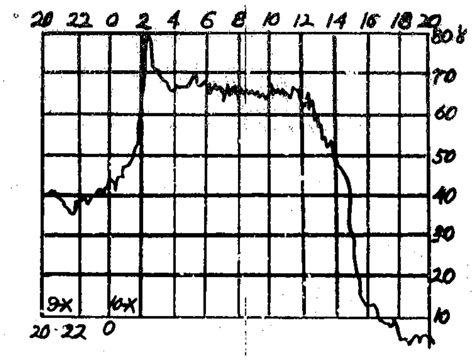

Figure 6. Variations of Z during a Meteorite Shower
(9-10 October 1946)

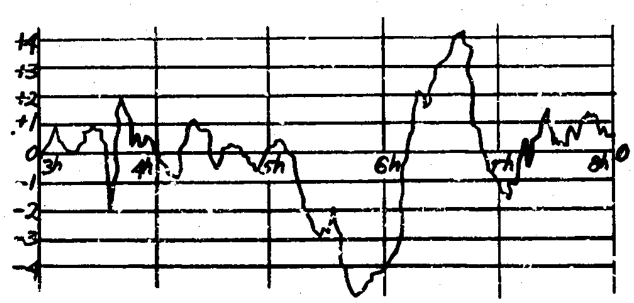

Figure 7. Variations of Z at the Time of Aurora Borealis (17 February 1947)
(scale in gammas)

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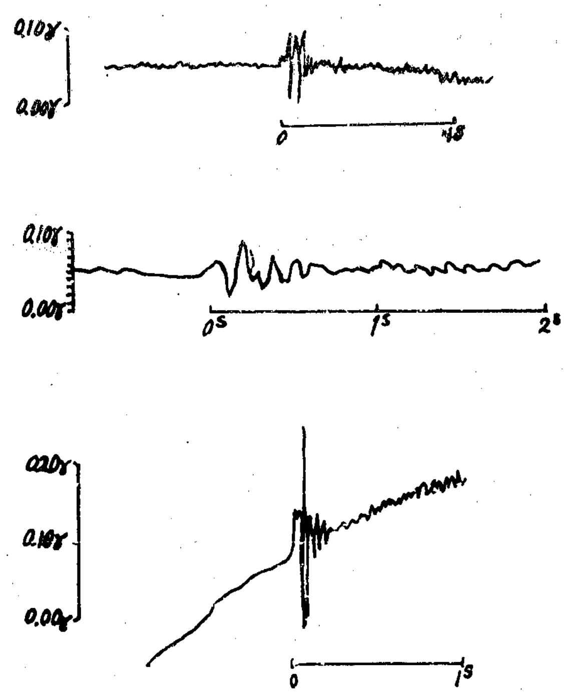

Figure 8. Variations of Z During Explosions

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